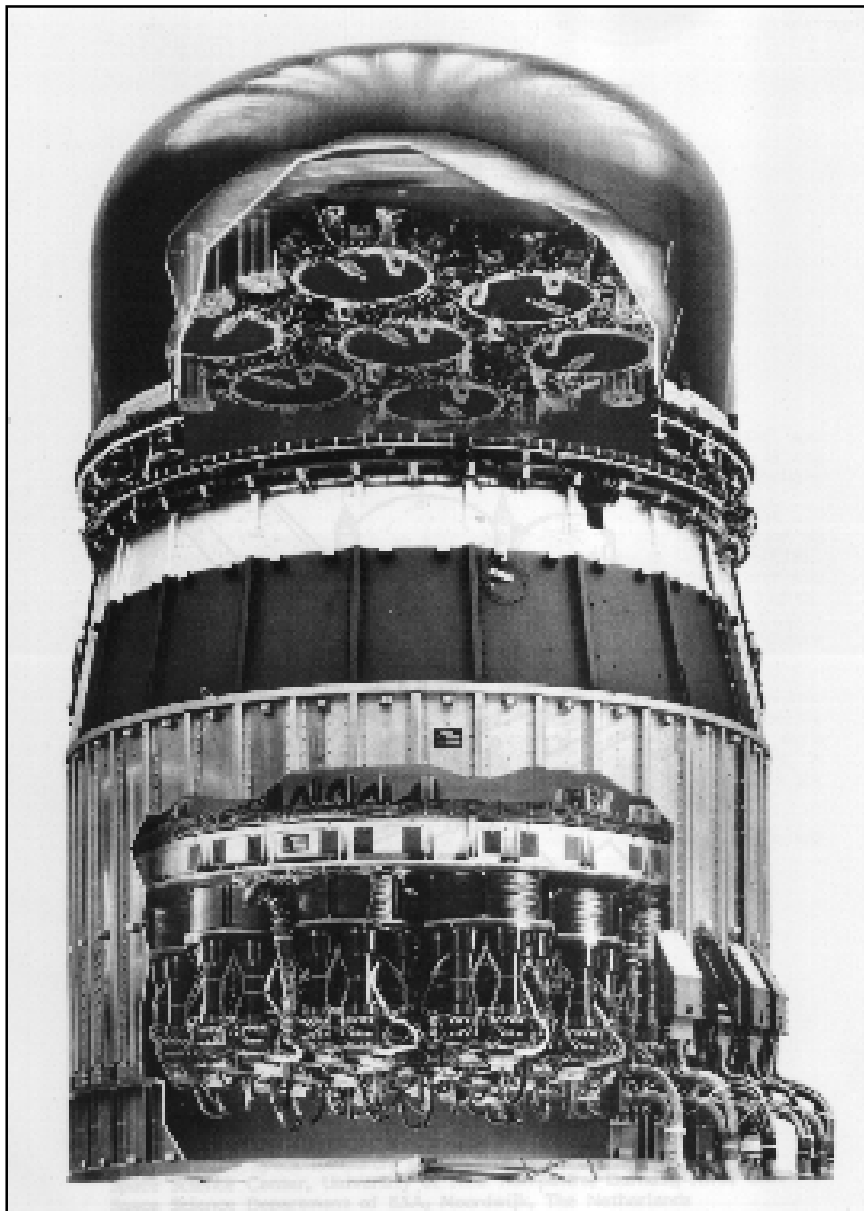


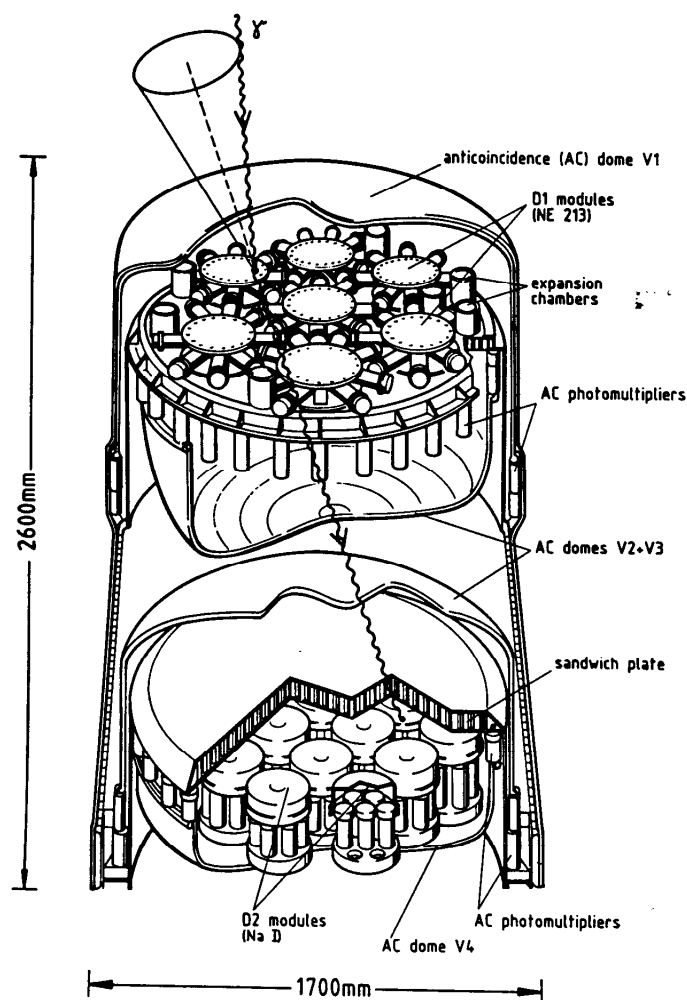
COMPTEL Simulations

A Review of What Has Been Done for COMPTEL

Mark McConnell, UNH



COMPTEL Description



- event location (x,y) in D1
- energy deposit in D1
- pulse-shape in D1
- time-of-flight (ToF) from D1 to D2
- event location (x,y) in D2
- energy deposit in D2
- absolute time (1/8 msec)

COMPTEL Simulations

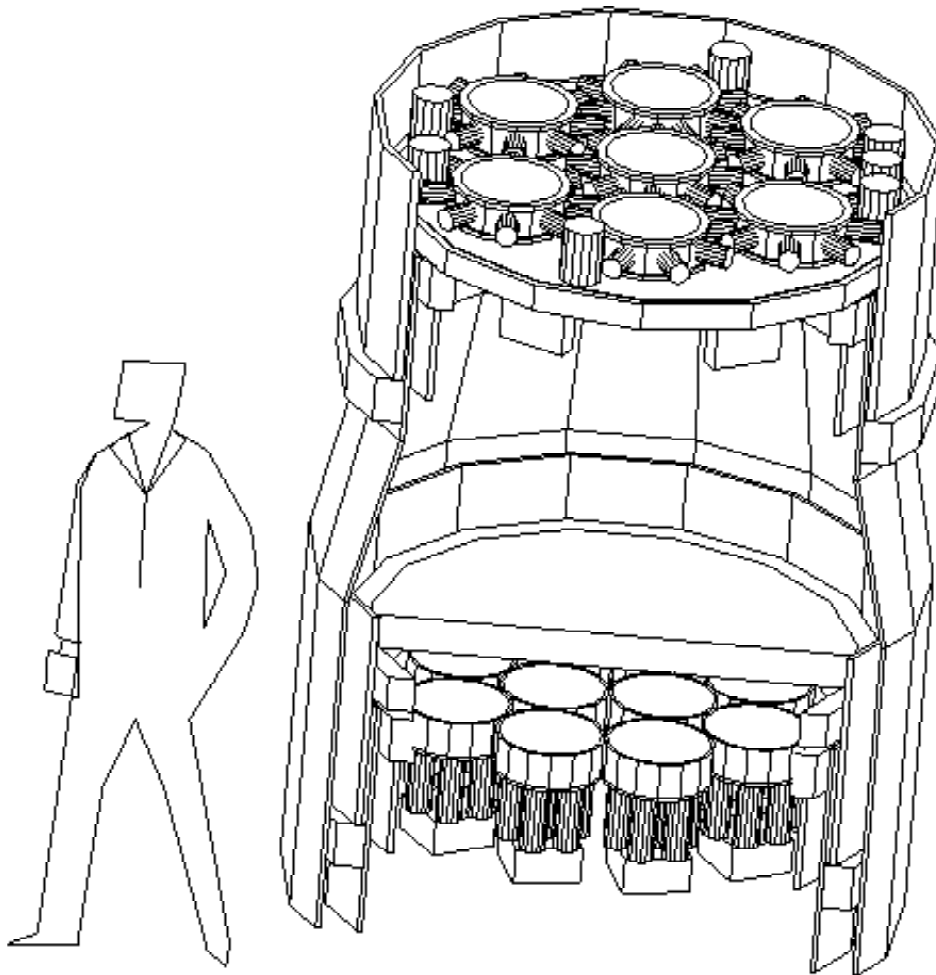
COMPTEL Monte Carlo code based on GEANT3.

Developed largely at UNH, starting ~1982.

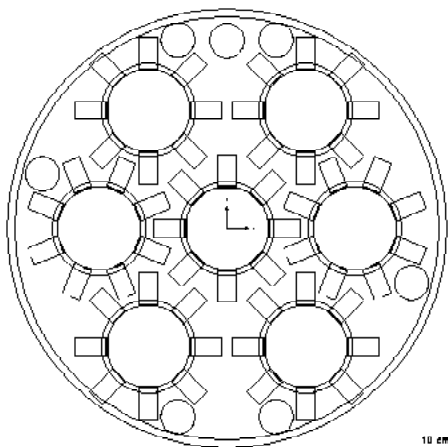
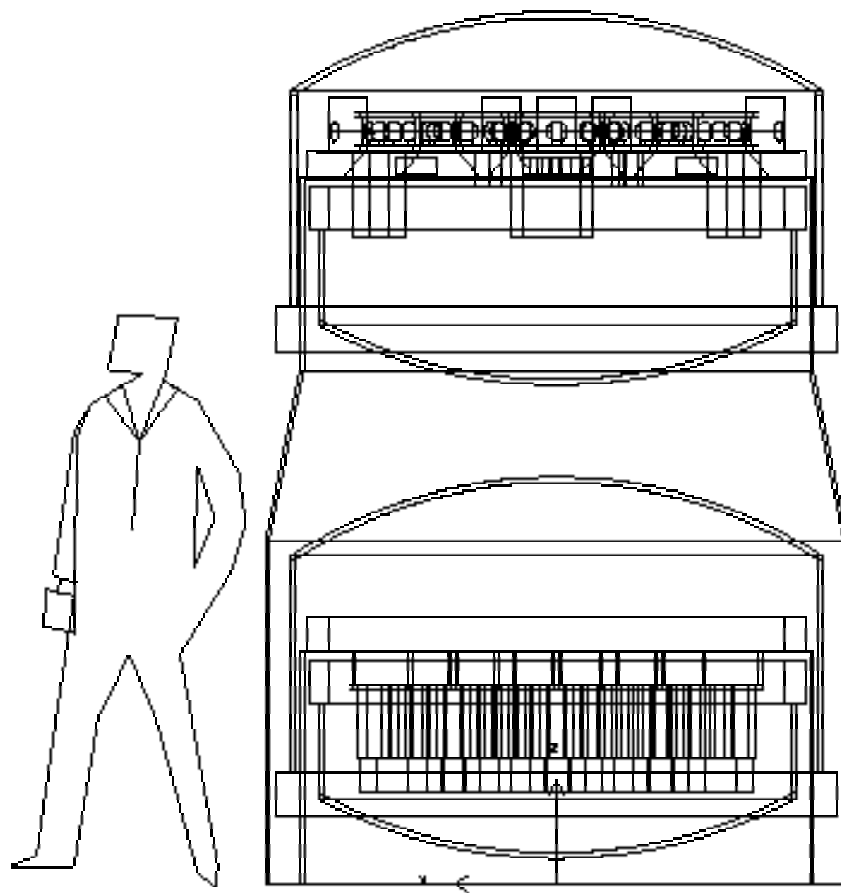
Major players: Dan Morris, Marc Kippen, Cheenu Kappadath, Georg Weidenspointner.

Only COMPTEL itself is included in the simulations.

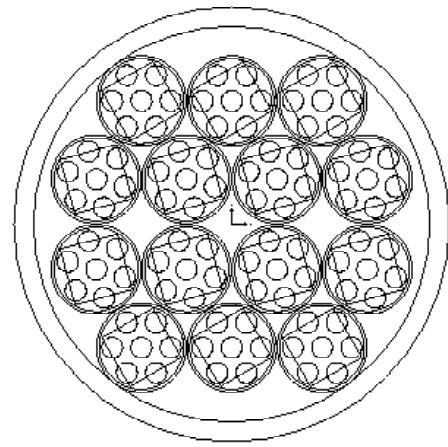
The “CGRO mass model” was never used.



COMPTEL Mass Model



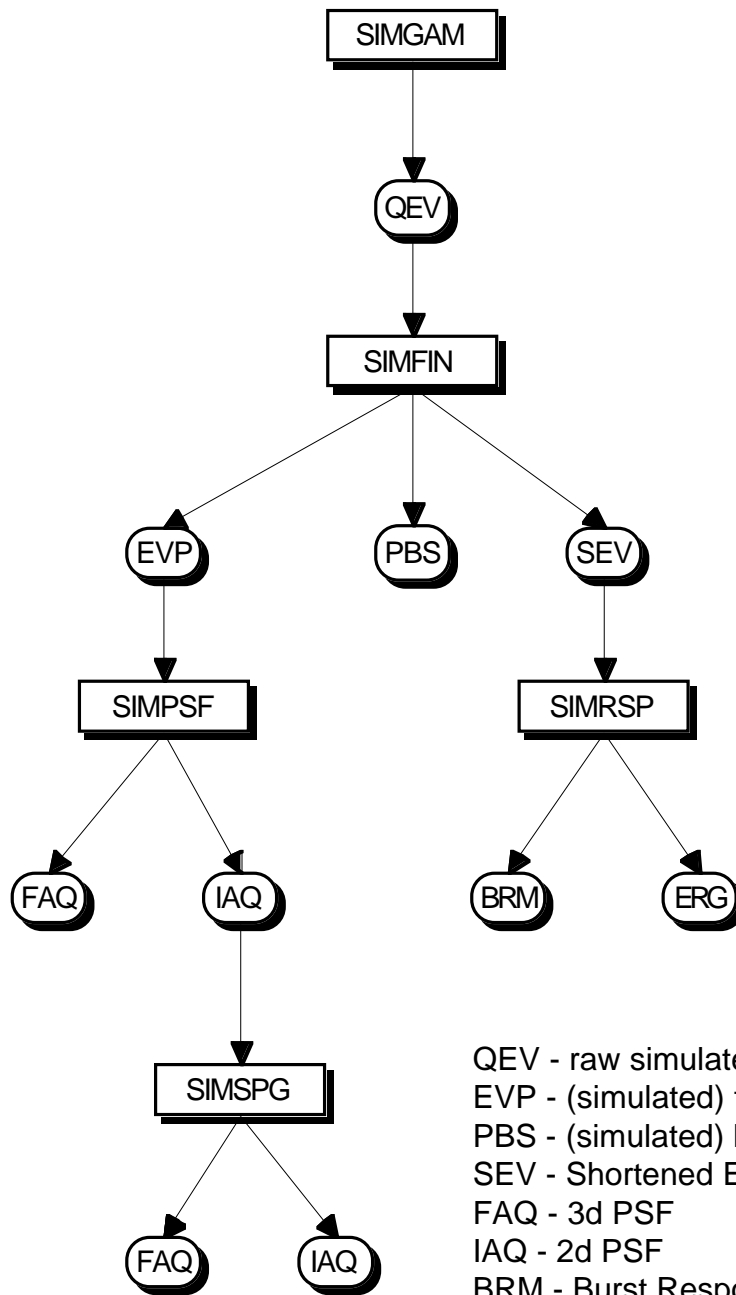
D1 Assembly



D2 Assembly

COMPTEL Simulations

Standard (Brute Force) Approach



QEV - raw simulated events

EVP - (simulated) telescope events

PBS - (simulated) burst data

SEV - Shortened EVP data (with input energy)

FAQ - 3d PSF

IAQ - 2d PSF

BRM - Burst Response Matrix

ERG - Energy Response Matrix telescope data)

COMPTEL PSF Synthesis

In order to save processing time, we developed an approach to PSF synthesis.

This approach involved the generation of a library of monoenergetic PSFs.

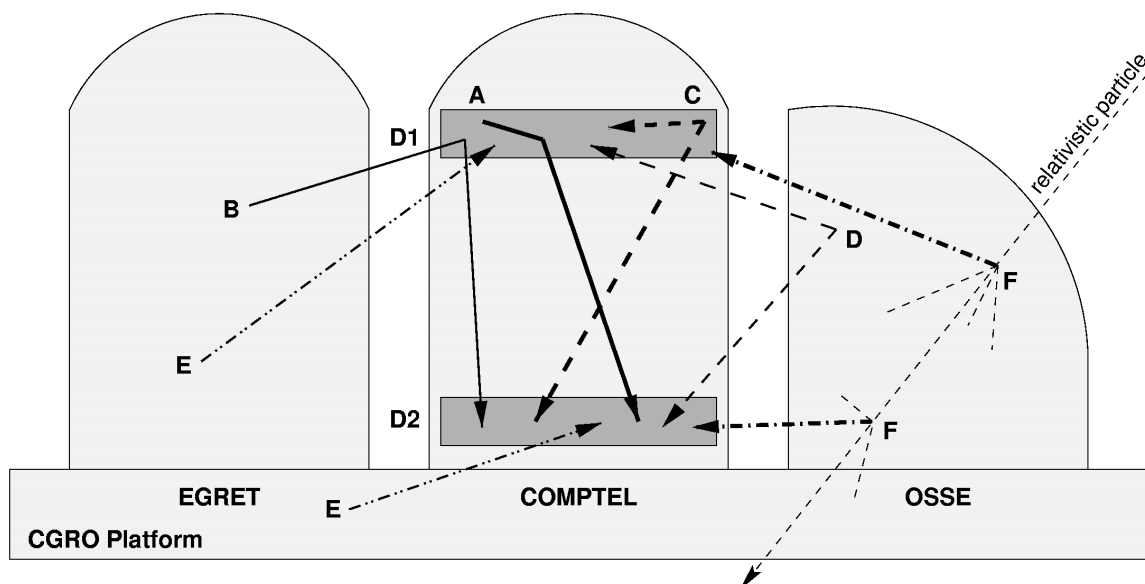
These monoenergetic PSFs were spaced in energy at 0.5σ of the energy resolution and with varying normalizations that provided appropriate statistics for a range of power-law spectra.

This approach was useful for varying the input energy spectrum of the PSF.

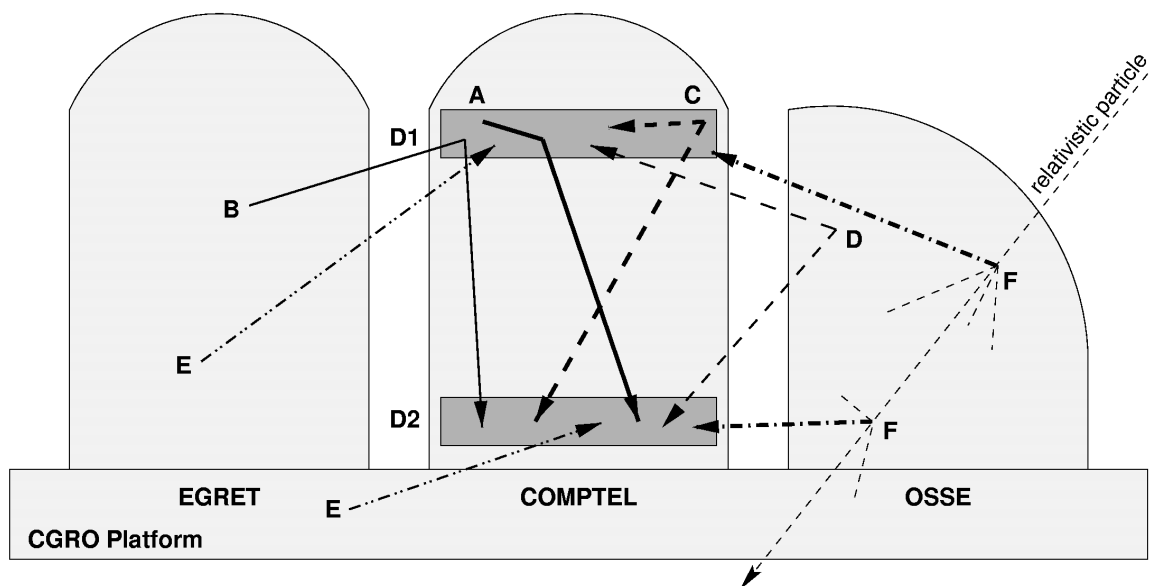
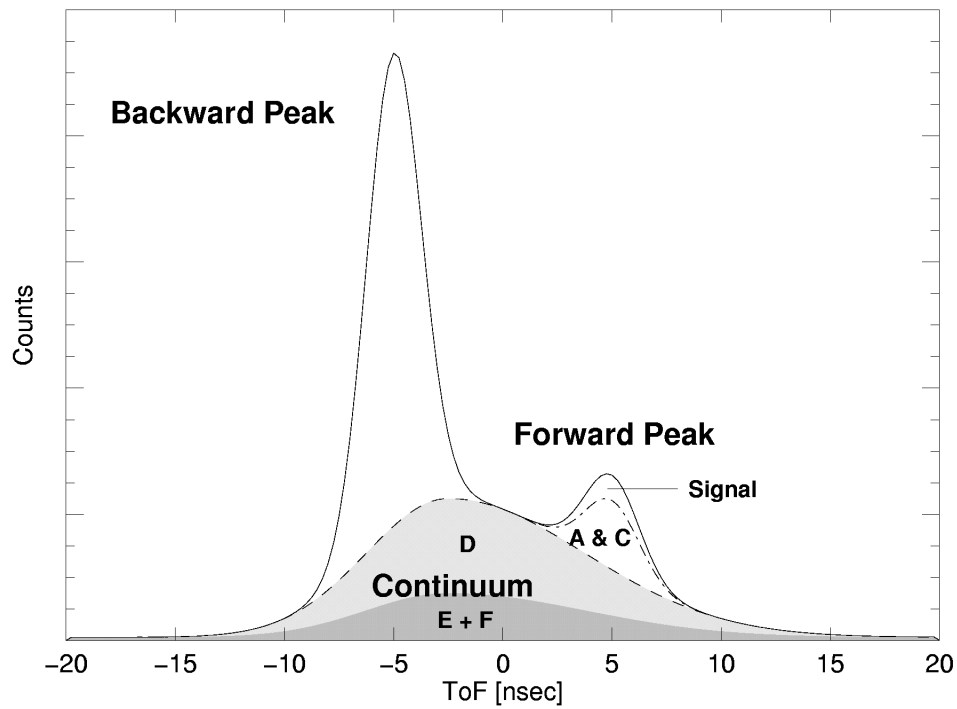
If other parameters were varied, however, this approach became awkward.

Types of Background Events

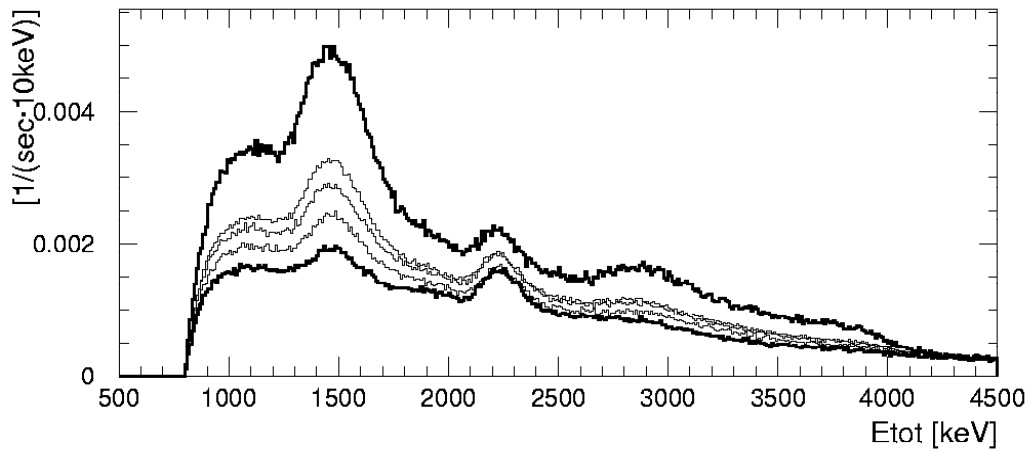
- A, B Internally-generated photons.
Ex : thermal neutron capture (2.2 MeV), ^{40}K (1.46 MeV)
- C Two photons spatially and temporally correlated.
Also known as “cascade events”.
Ex : ^{24}Na (1.37, 2.75 MeV), ^{22}Na (0.511, 1.275 MeV),
 ^{28}Al (1.78 MeV, β^-)
- D Two photons spatially and temporally uncorrelated.
Also known as “random coincidences”.
- E Two photons which are spatially uncorrelated, but temporally correlated.
Ex : cosmic ray generating ≥ 2 photons



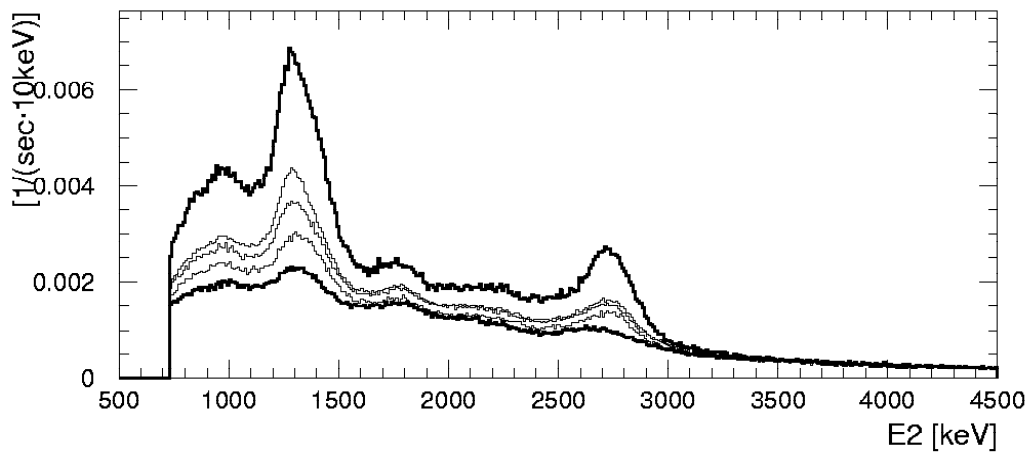
Contributions to ToF Spectrum



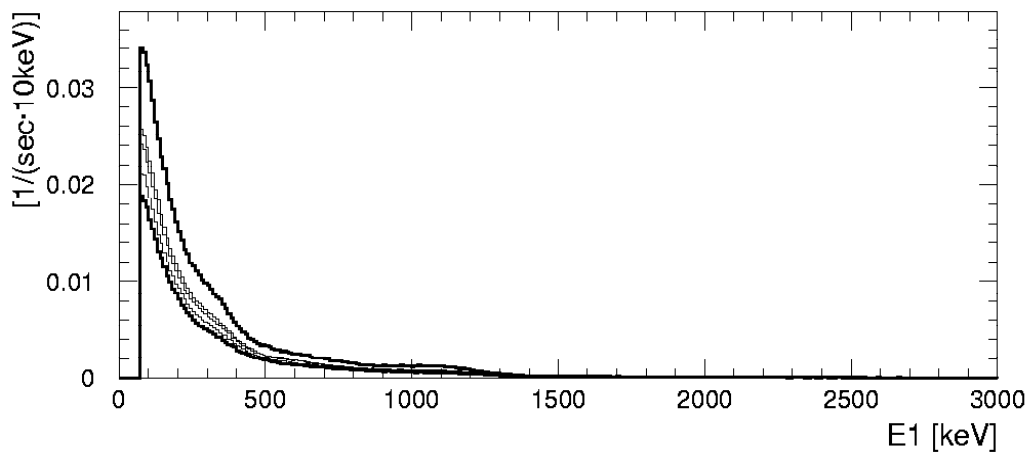
Background Spectra vs. Time



**total
energy-loss**

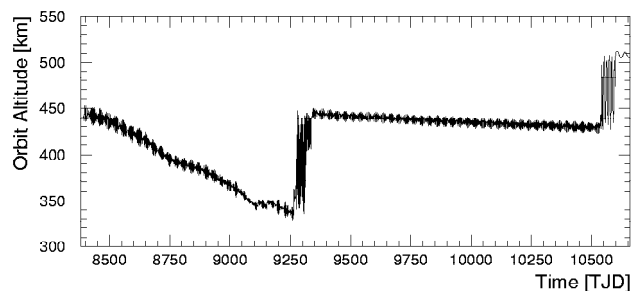
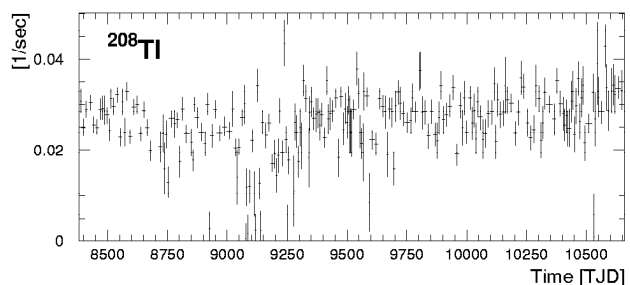
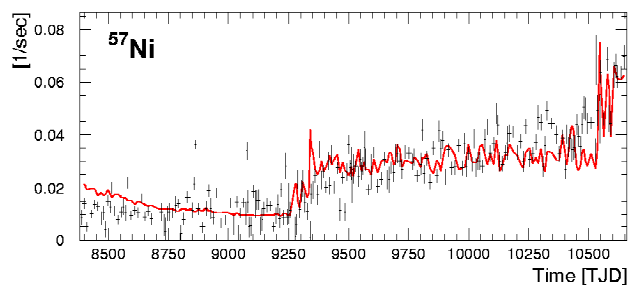
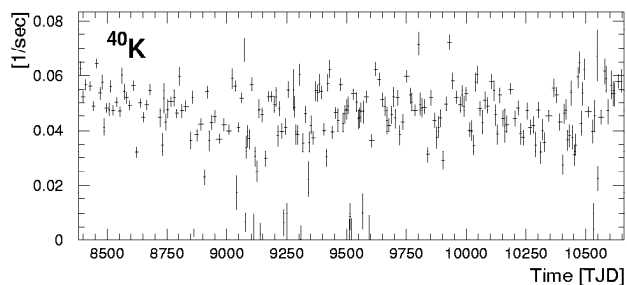
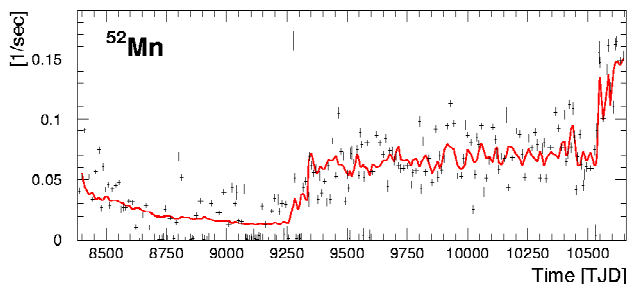
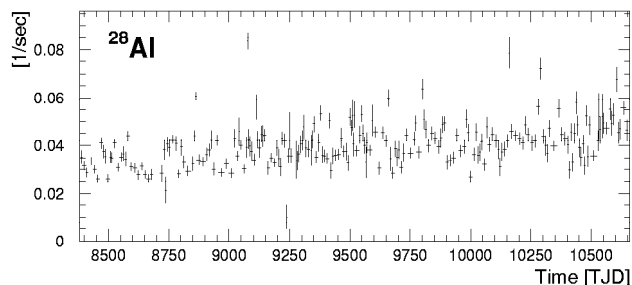
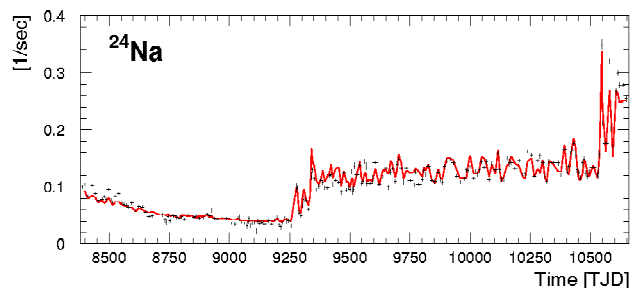
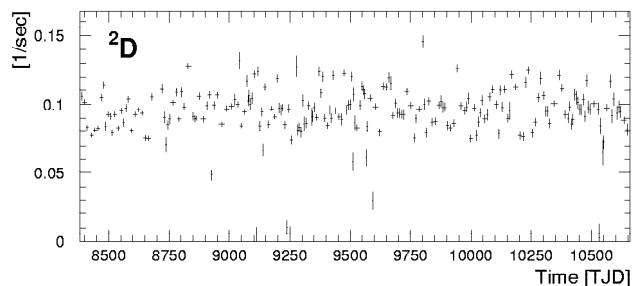
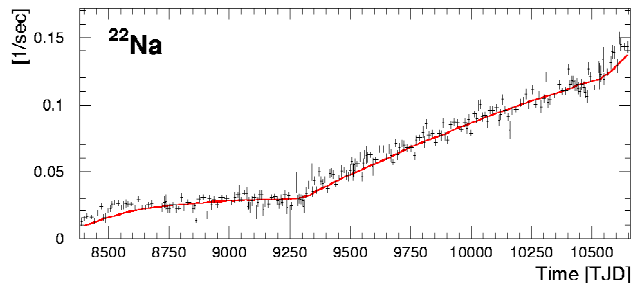


**D2
energy-loss**



**D1
energy-loss**

Background Time-Dependence



Observed Background Lines

A summary of the isotopes identified in the COMPTTEL background.

Isotope	Half-Life	Decay Modes and Photon Energies [MeV]	Main Production Channels
^2D	prompt	2.224	$^1\text{H}(\text{n}_{\text{ther}}, \gamma)$
^{22}Na	2.6 y	β^+ (91%): 0.511, 1.275 EC (9%) : 1.275	$^{27}\text{Al}(\text{p}, 3\text{p}3\text{n})$, $\text{Si}(\text{p}, 4\text{p}3\text{n})$
^{24}Na	14.96 h	β^- : 1.37, 2.75	$^{27}\text{Al}(\text{n}, \alpha)$, $^{27}\text{Al}(\text{p}, 3\text{pn})$
^{28}Al	2.2 min	β^- : 1.779	$^{27}\text{Al}(\text{n}_{\text{ther}}, \gamma)$
^{40}K	1.28×10^9 y	EC (10.7%): 1.461	natural
^{52}Mn	5.6 d	EC (64%): 0.744, 0.935, 1.434 β^+ (27%): 0.511, 0.744, 0.935, 1.434	$\text{Fe}(\text{p}, \text{x})$, $\text{Cr}(\text{p}, \text{x})$, $\text{Ni}(\text{p}, \text{x})$
^{57}Ni	35.6 h	β^+ (35%): 0.511, 1.377 EC (30%): 1.377	$\text{Ni}(\text{p}, \text{x})$, $\text{Cu}(\text{p}, \text{x})$
^{208}Tl (^{232}Th)	1.4×10^{10} y	β^- (50%): 0.583, 2.614 β^- (25%): 0.511, 0.583, 2.614	natural

Source materials includes:

- 1) “natural” radio-activities**
- 2) liquid scintillator (n-capture)**
- 3) aluminum support structure (^{27}Al spallation)**
- 4) Cu, Ni, Fe, Cr components**

Background Line Simulations

Special modes defined for simulating various activation species.

Source distribution is first defined. Usually, this corresponds to some well-defined mass structure within COMPTTEL (e.g., D1 liquid scintillator).

Decay site within volume is picked at random.

Decay radiations (single photon, two-photon, single photon plus β , etc.) are generated at that point with appropriate energies and angular distributions.

Simulated Neutron Capture in D1

Type A : 2.223 MeV photons scatter from D1 to D2
Simulated as source within D1 liquid scintillator.

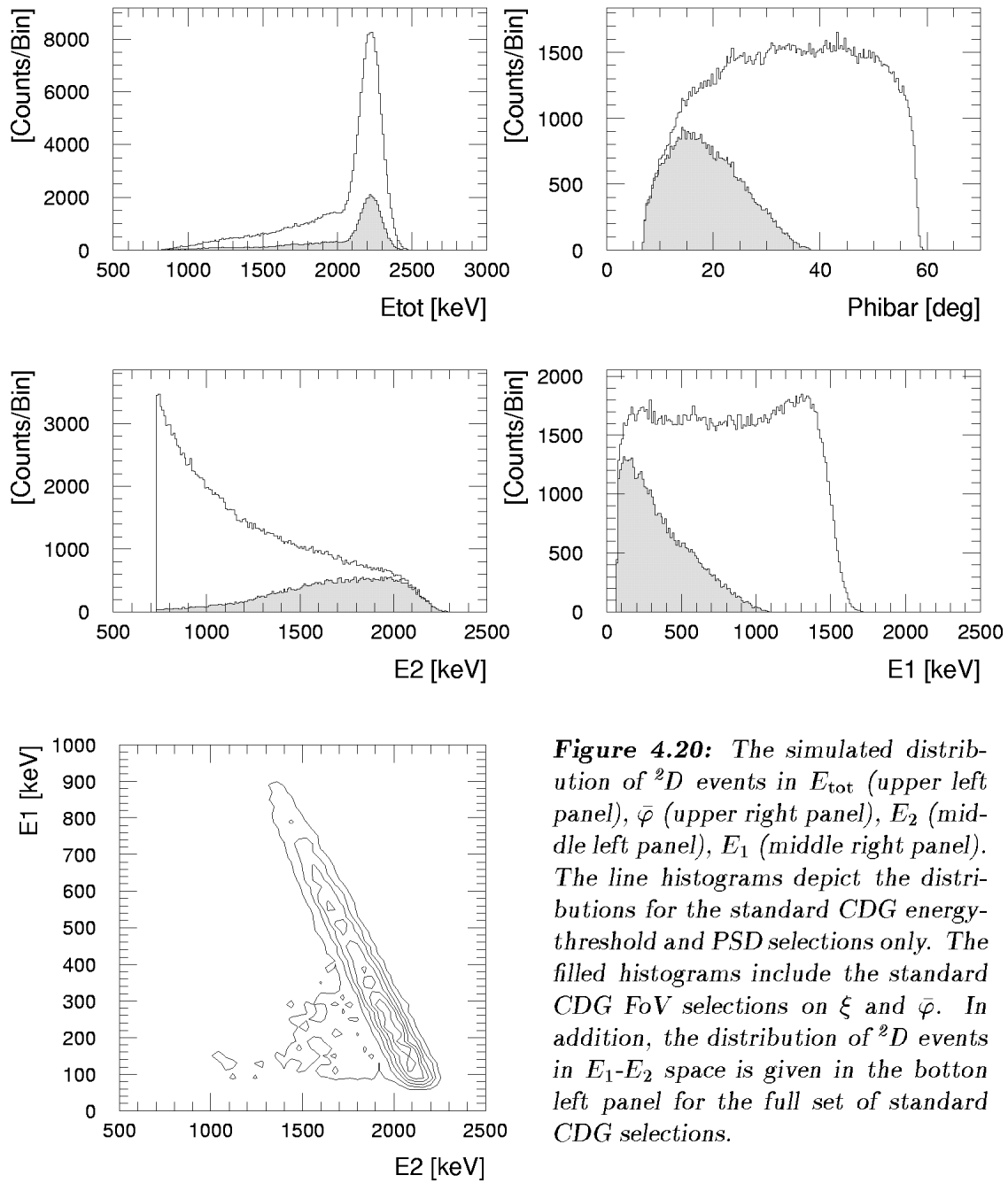


Figure 4.20: The simulated distribution of 2D events in E_{tot} (upper left panel), $\bar{\varphi}$ (upper right panel), E_2 (middle left panel), E_1 (middle right panel). The line histograms depict the distributions for the standard CDG energy-threshold and PSD selections only. The filled histograms include the standard CDG FoV selections on ξ and $\bar{\varphi}$. In addition, the distribution of 2D events in E_1 - E_2 space is given in the bottom left panel for the full set of standard CDG selections.

Simulated ^{24}Na

Type C (cascade) : β^- followed by 1.37 and 2.75 MeV photons
Simulated as source within upper Al structure.

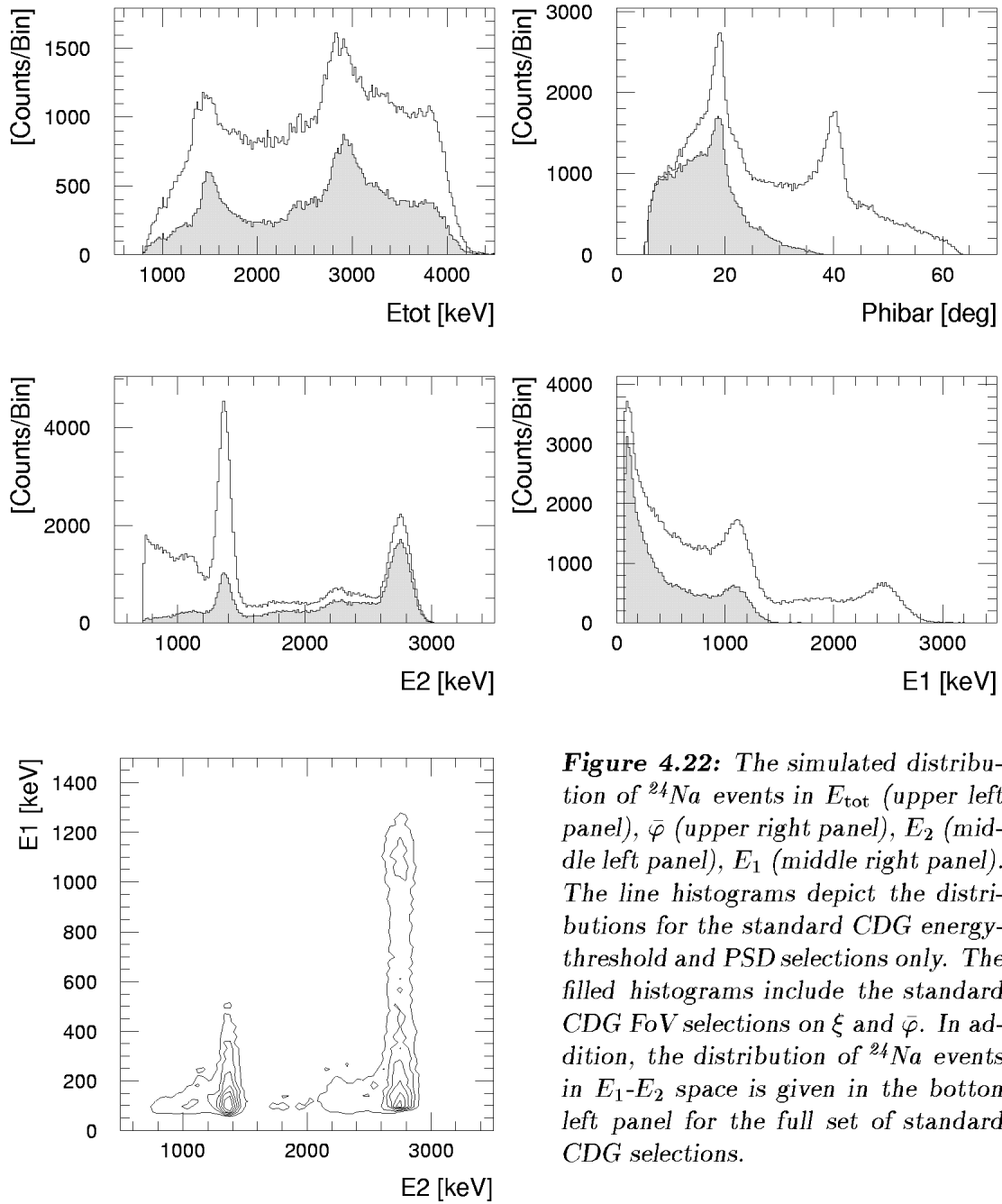


Figure 4.22: The simulated distribution of ^{24}Na events in E_{tot} (upper left panel), $\bar{\varphi}$ (upper right panel), E_2 (middle left panel), E_1 (middle right panel). The line histograms depict the distributions for the standard CDG energy-threshold and PSD selections only. The filled histograms include the standard CDG FoV selections on ξ and $\bar{\varphi}$. In addition, the distribution of ^{24}Na events in E_1 - E_2 space is given in the bottom left panel for the full set of standard CDG selections.

Simulated ^{40}K

Type A: 1.46 MeV photons scatter from D1 to D2
Simulated as source within glass of D1 PMTs.

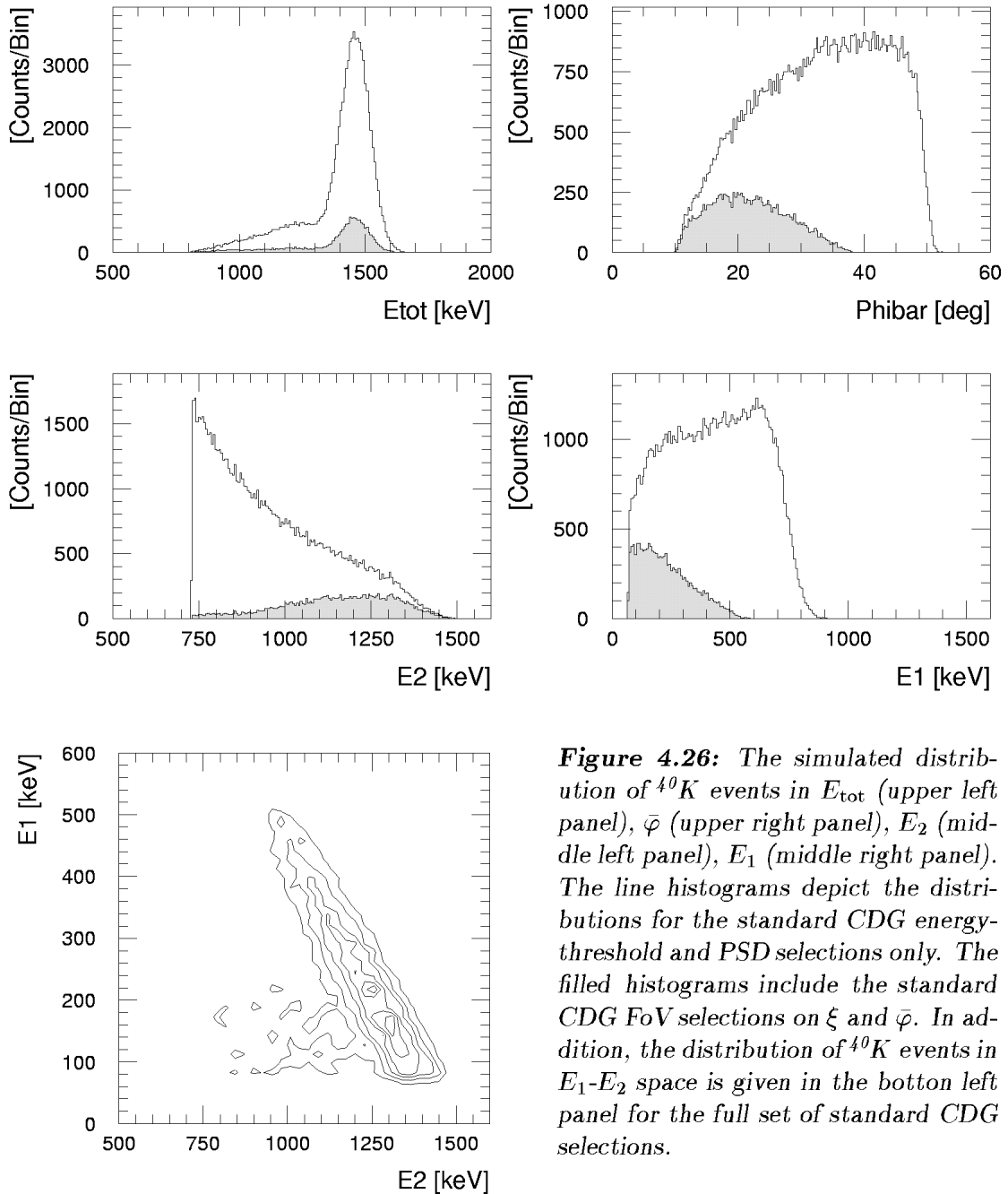


Figure 4.26: The simulated distribution of ^{40}K events in E_{tot} (upper left panel), $\bar{\varphi}$ (upper right panel), E_2 (middle left panel), E_1 (middle right panel). The line histograms depict the distributions for the standard CDG energy-threshold and PSD selections only. The filled histograms include the standard CDG FoV selections on ξ and $\bar{\varphi}$. In addition, the distribution of ^{40}K events in E_1 - E_2 space is given in the bottom left panel for the full set of standard CDG selections.

Simulated ^{22}Na

type C (cascade) : 0.511 MeV and 1.275 MeV photons
Simulated as source within upper Al structure.

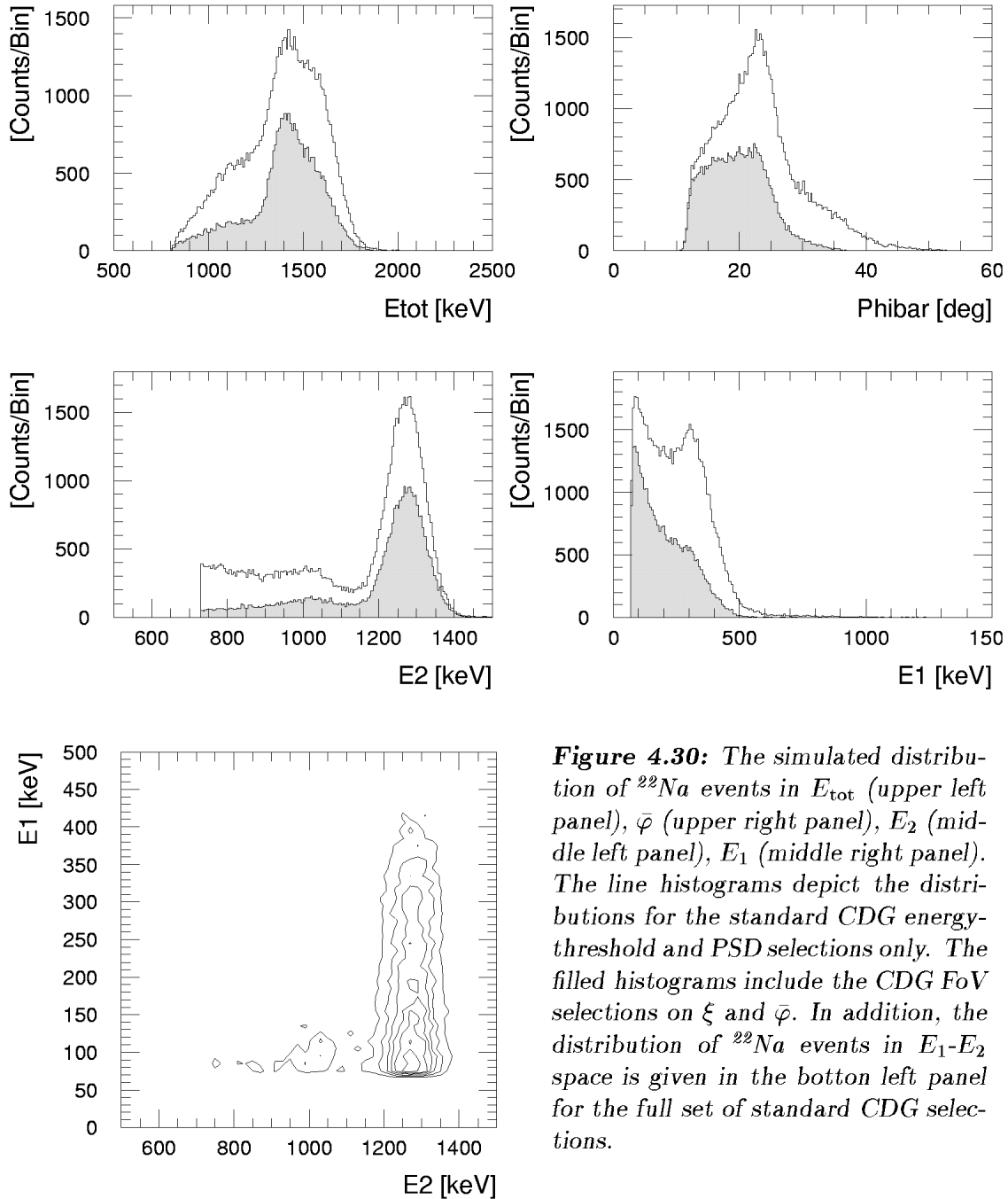


Figure 4.30: The simulated distribution of ^{22}Na events in E_{tot} (upper left panel), $\bar{\varphi}$ (upper right panel), E_2 (middle left panel), E_1 (middle right panel). The line histograms depict the distributions for the standard CDG energy-threshold and PSD selections only. The filled histograms include the CDG FoV selections on ξ and $\bar{\varphi}$. In addition, the distribution of ^{22}Na events in E_1 - E_2 space is given in the bottom left panel for the full set of standard CDG selections.

Simulated ^{28}Al

Type C (cascade) : β^- followed by 1.78 MeV photon
Simulated as source within upper aluminum structure.

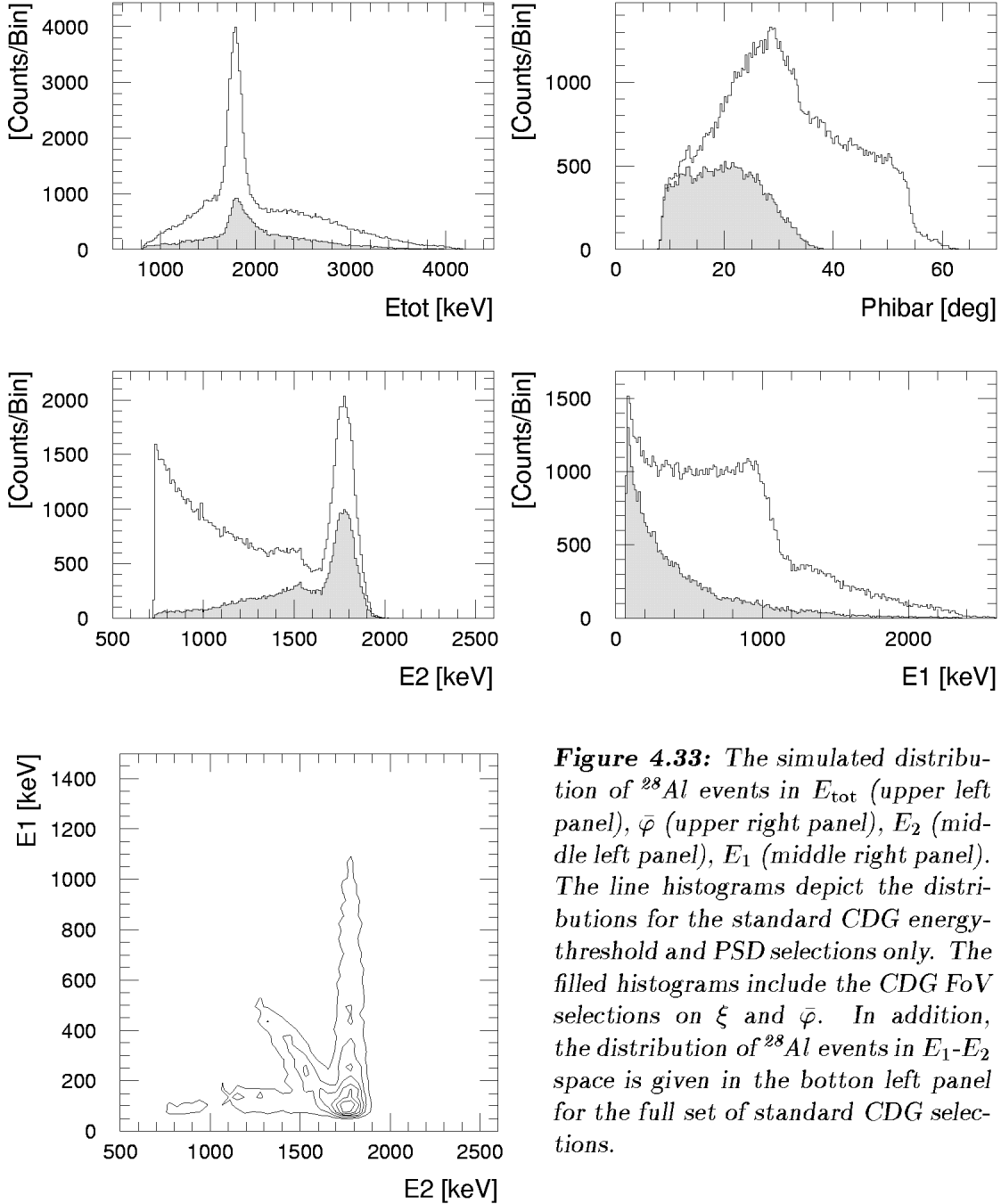


Figure 4.33: The simulated distribution of ^{28}Al events in E_{tot} (upper left panel), $\bar{\varphi}$ (upper right panel), E_2 (middle left panel), $\bar{\varphi}$ (upper right panel), E_1 (middle right panel). The line histograms depict the distributions for the standard CDG energy-threshold and PSD selections only. The filled histograms include the CDG FoV selections on ξ and $\bar{\varphi}$. In addition, the distribution of ^{28}Al events in E_1 - E_2 space is given in the bottom left panel for the full set of standard CDG selections.

Simulated ^{208}Tl

Type C (cascade) : β^- followed by 2.61 MeV photon
Simulated as source within glass of D1 PMTs.

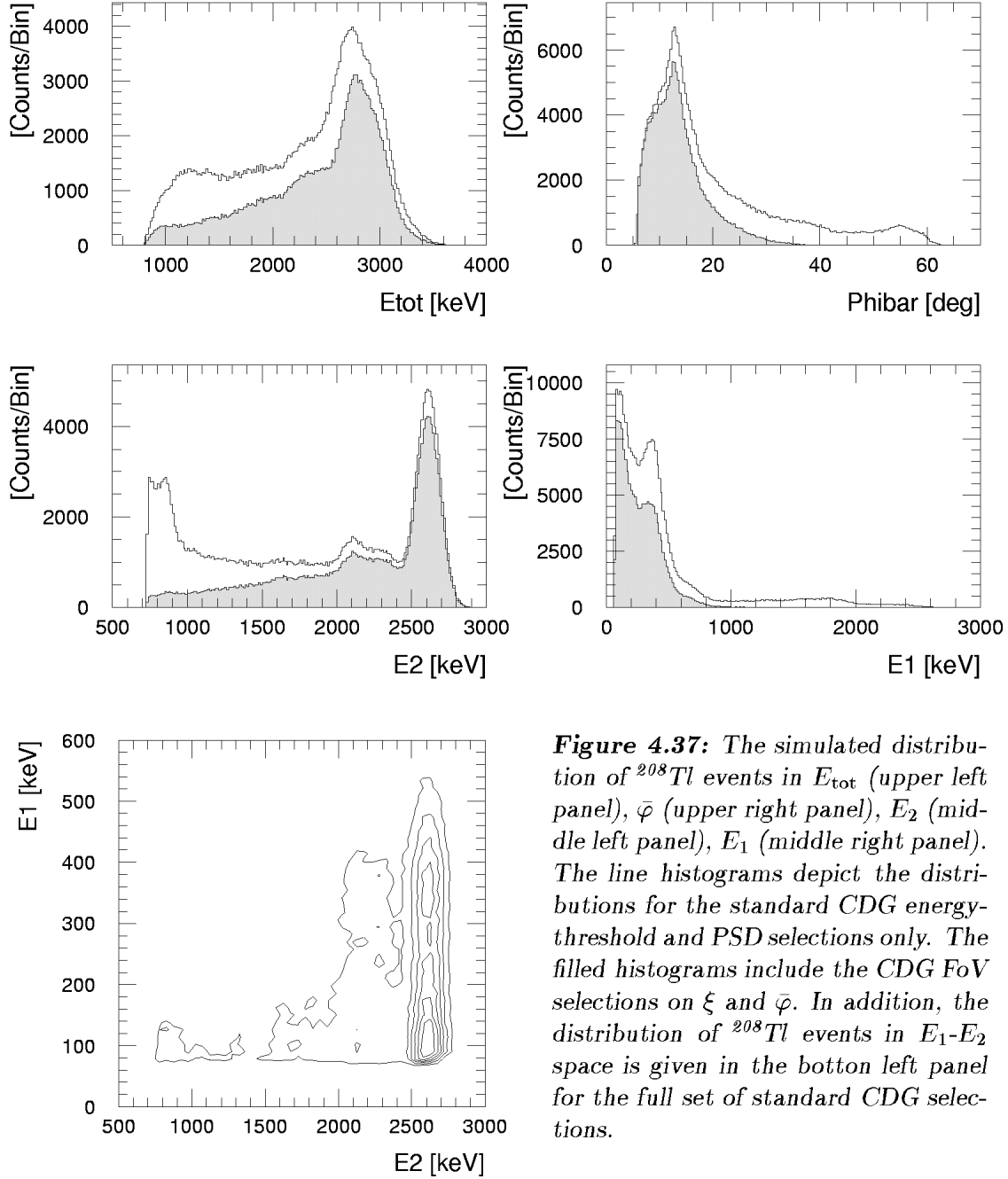


Figure 4.37: The simulated distribution of ^{208}Tl events in E_{tot} (upper left panel), $\bar{\varphi}$ (upper right panel), E_2 (middle left panel), E_1 (middle right panel). The line histograms depict the distributions for the standard CDG energy-threshold and PSD selections only. The filled histograms include the CDG FoV selections on ξ and $\bar{\varphi}$. In addition, the distribution of ^{208}Tl events in E_1 - E_2 space is given in the bottom left panel for the full set of standard CDG selections.

Simulated ^{52}Mn

Type C (cascade) : β^+ followed by 0.74, 0.94 and 1.43 MeV photons
Simulated as source within Fe, Cr and Ni components of D1.

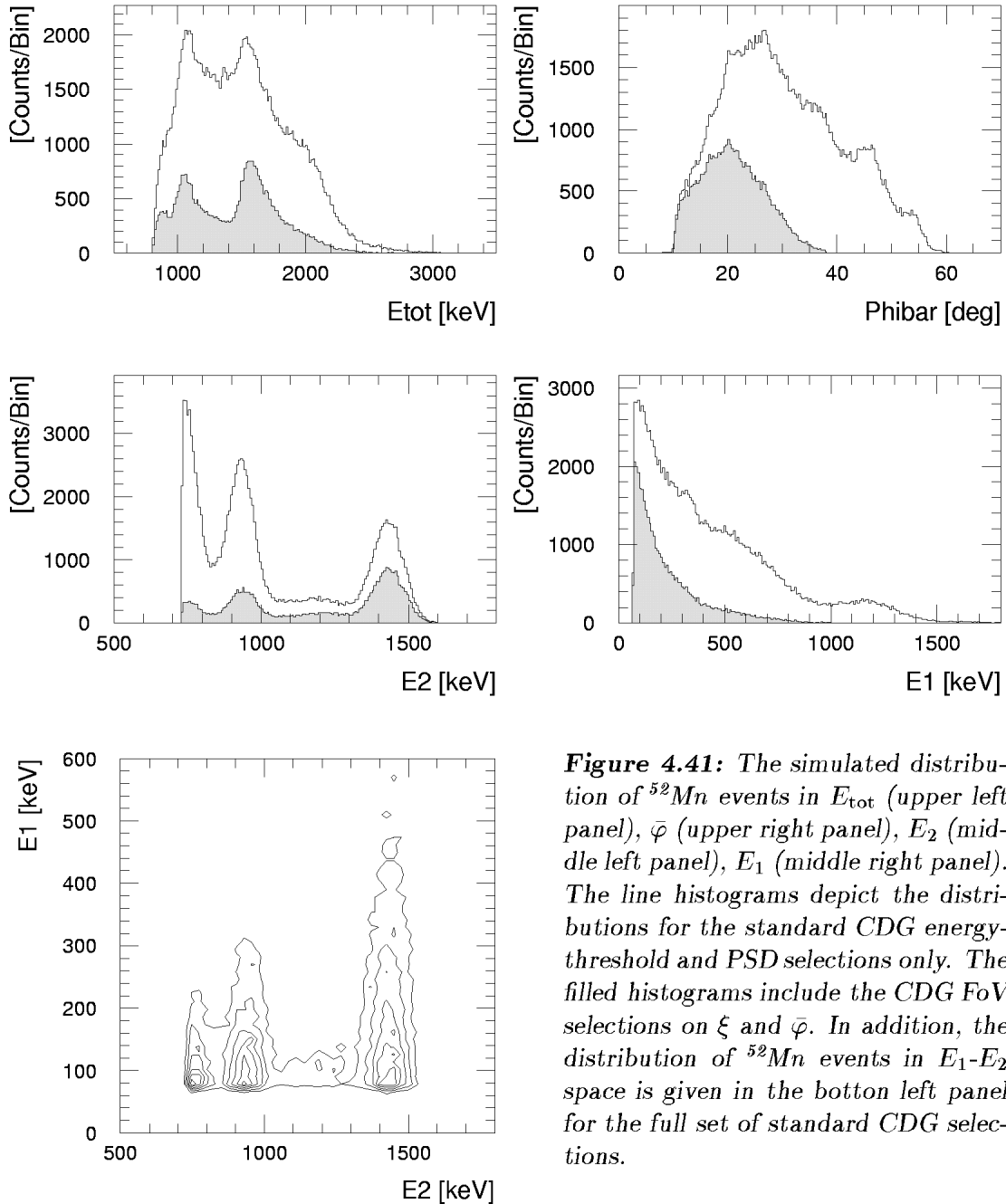


Figure 4.41: The simulated distribution of ^{52}Mn events in E_{tot} (upper left panel), $\bar{\varphi}$ (upper right panel), E_2 (middle left panel), $\bar{\varphi}$ (upper right panel), E_1 (middle right panel). The line histograms depict the distributions for the standard CDG energy-threshold and PSD selections only. The filled histograms include the CDG FoV selections on ξ and $\bar{\varphi}$. In addition, the distribution of ^{52}Mn events in E_1 - E_2 space is given in the bottom left panel for the full set of standard CDG selections.

Simulated ^{57}Ni

Type C (cascade) : β^+ followed by 1.377 MeV photon
Simulated as source within Ni and Cu components of D1.

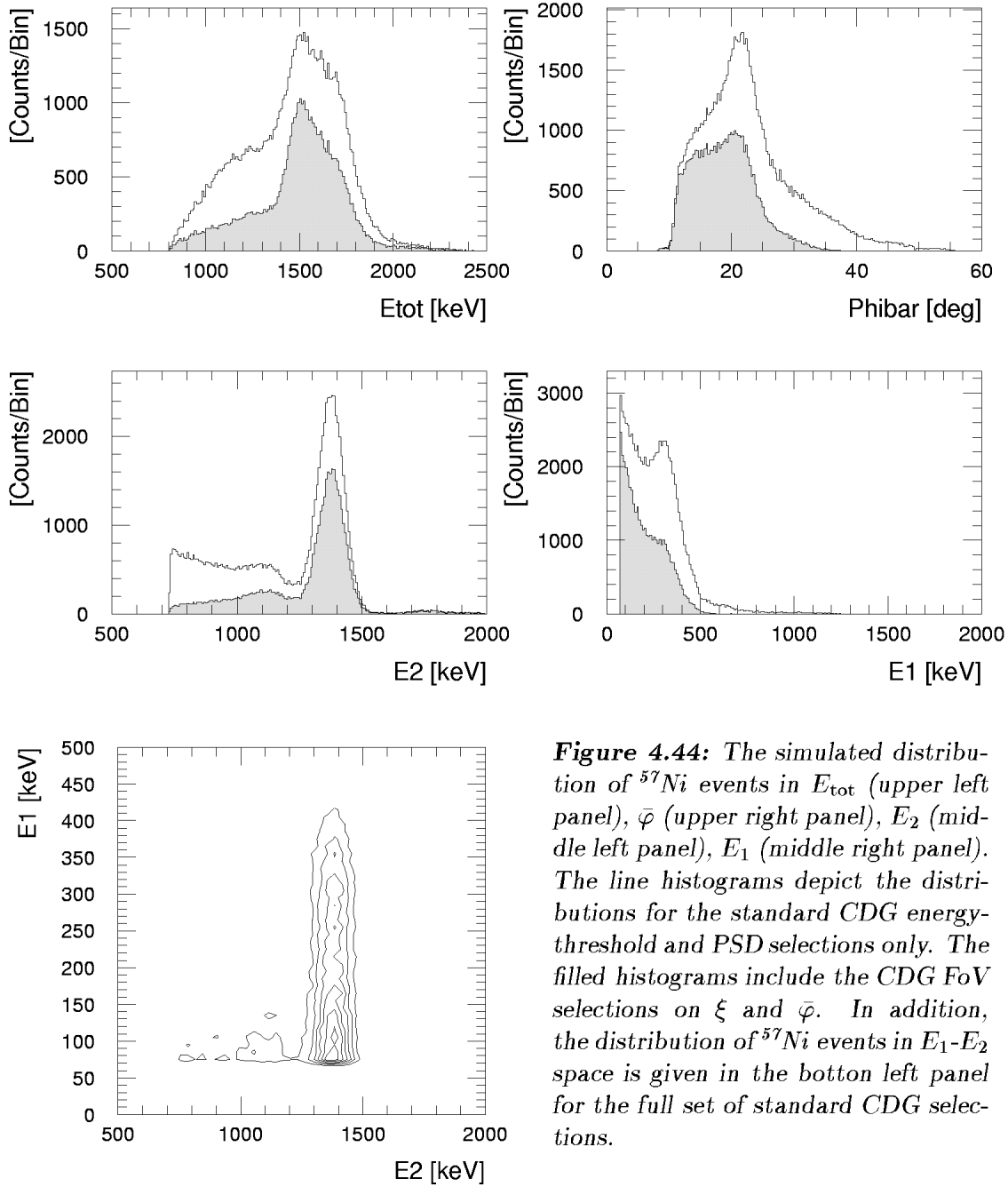


Figure 4.44: The simulated distribution of ^{57}Ni events in E_{tot} (upper left panel), $\bar{\varphi}$ (upper right panel), E_2 (middle left panel), $\bar{\varphi}$ (upper right panel), E_1 (middle right panel). The line histograms depict the distributions for the standard CDG energy-threshold and PSD selections only. The filled histograms include the CDG FoV selections on ξ and $\bar{\varphi}$. In addition, the distribution of ^{57}Ni events in E_1 - E_2 space is given in the bottom left panel for the full set of standard CDG selections.

Simulated ^{27}Mg

Type C (cascade) : 0.844 and 1.014 MeV photons
 Simulated as source within upper Al structure.
 (found only after SAA passage)

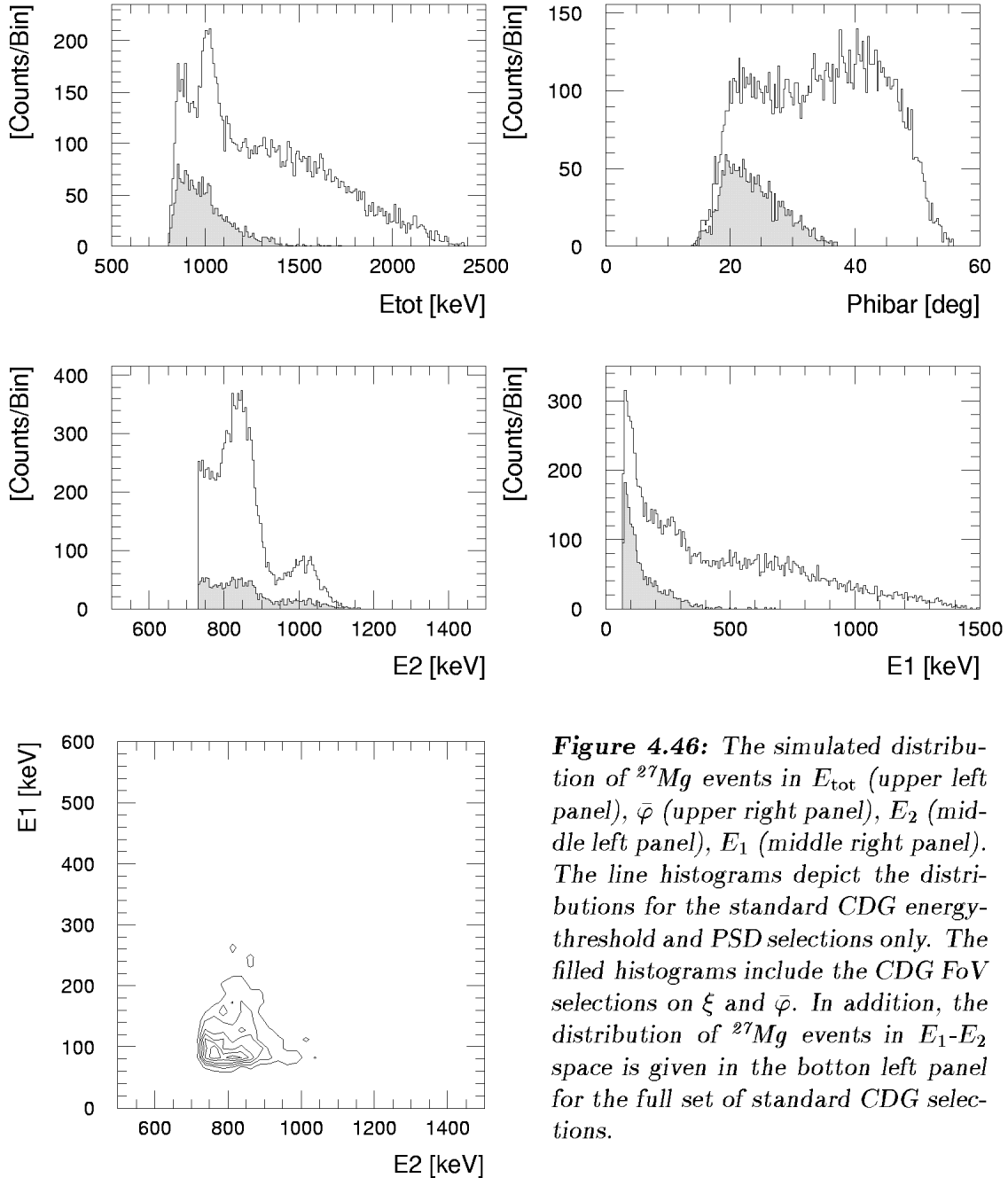


Figure 4.46: The simulated distribution of ^{27}Mg events in E_{tot} (upper left panel), $\bar{\varphi}$ (upper right panel), E_2 (middle left panel), E_1 (middle right panel). The line histograms depict the distributions for the standard CDG energy-threshold and PSD selections only. The filled histograms include the CDG FoV selections on ξ and $\bar{\varphi}$. In addition, the distribution of ^{27}Mg events in E_1 - E_2 space is given in the bottom left panel for the full set of standard CDG selections.

Line Identifications

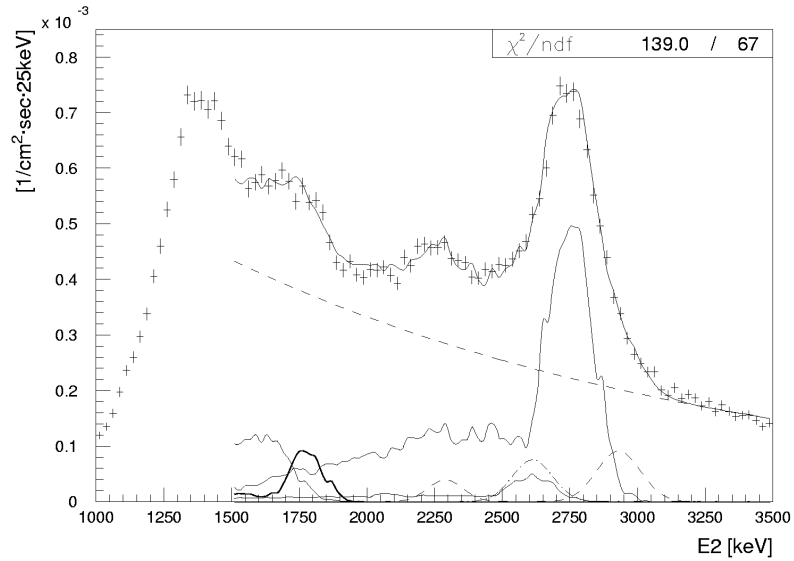


Figure 5.6: An example for a fit of the second E_2 spectrum, which is used to determine the activity from ^{28}Al . In addition to the total fit, the templates for ^2D (the line-feature at ~ 1.6 MeV, fixed), ^{28}Al (the 1.78 MeV line), ^{24}Na (the strong line at 2.75 MeV, fixed) and ^{208}Tl (the weaker line at 2.61 MeV, fixed), the three unidentified lines (dashed, dashed-dotted, and dashed lines), and the exponential continuum are indicated.

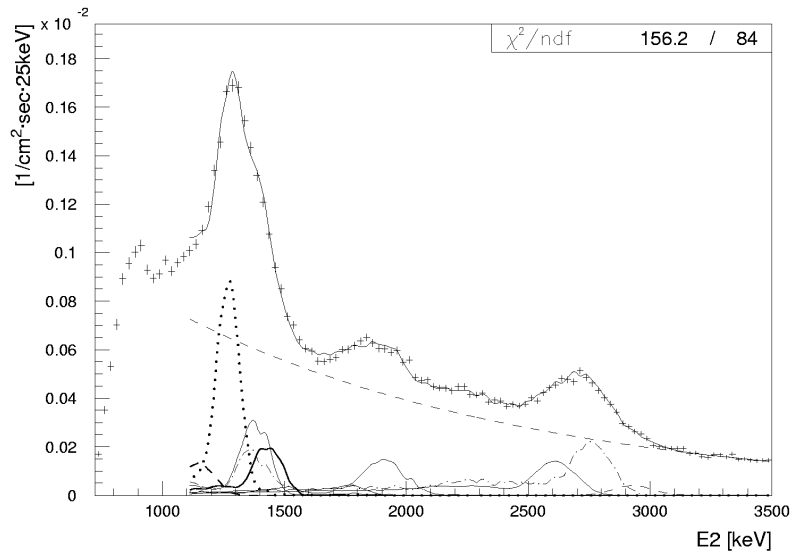


Figure 5.8: An example for a fit of the second E_2 spectrum, which is used to determine the activities from ^{22}Na (dotted line), ^{52}Mn (thick solid line), and ^{57}Ni (thin solid line). Also depicted are the fixed components (^2D : solid line at 1.9 MeV, ^{24}Na : dash-dotted line, ^{28}Al : weak solid component below 1.9 MeV, ^{40}K : dashed line, ^{208}Tl : solid line at 2.6 MeV), as well as the total fit, the energy continuum, and the unidentified 2.93 MeV line.

COMPTEL Simulation References

Kippen (1991)

PhD Thesis, University of New Hampshire

Monte Carlo Simulation of the COMPTEL Gamma-Ray Telescope

Stacy et al. (1996)

A&A Supp., 120, C691. (3rd Compton Symp.)

The Response of the CGRO COMPTEL Determined from Monte Carlo Simulation Studies

Kappadath (1998)

PhD Thesis, University of New Hampshire

Measurement of the Cosmic Diffuse Gamma-Ray Spectrum from 800 keV to 30 MeV

http://www.gro.unh.edu/users/ckappada/thesis_stuff/thesis.html

Weidenspointner (1999)

PhD thesis, Technische Universität München

The Origin of the Cosmic Gamma-Ray Background in the COMPTEL Energy Range

<http://www.gamma.mpe-garching.mpg.de/~ggw/phd.html>

Kappadath (2000)

In preparation (for ApJ)

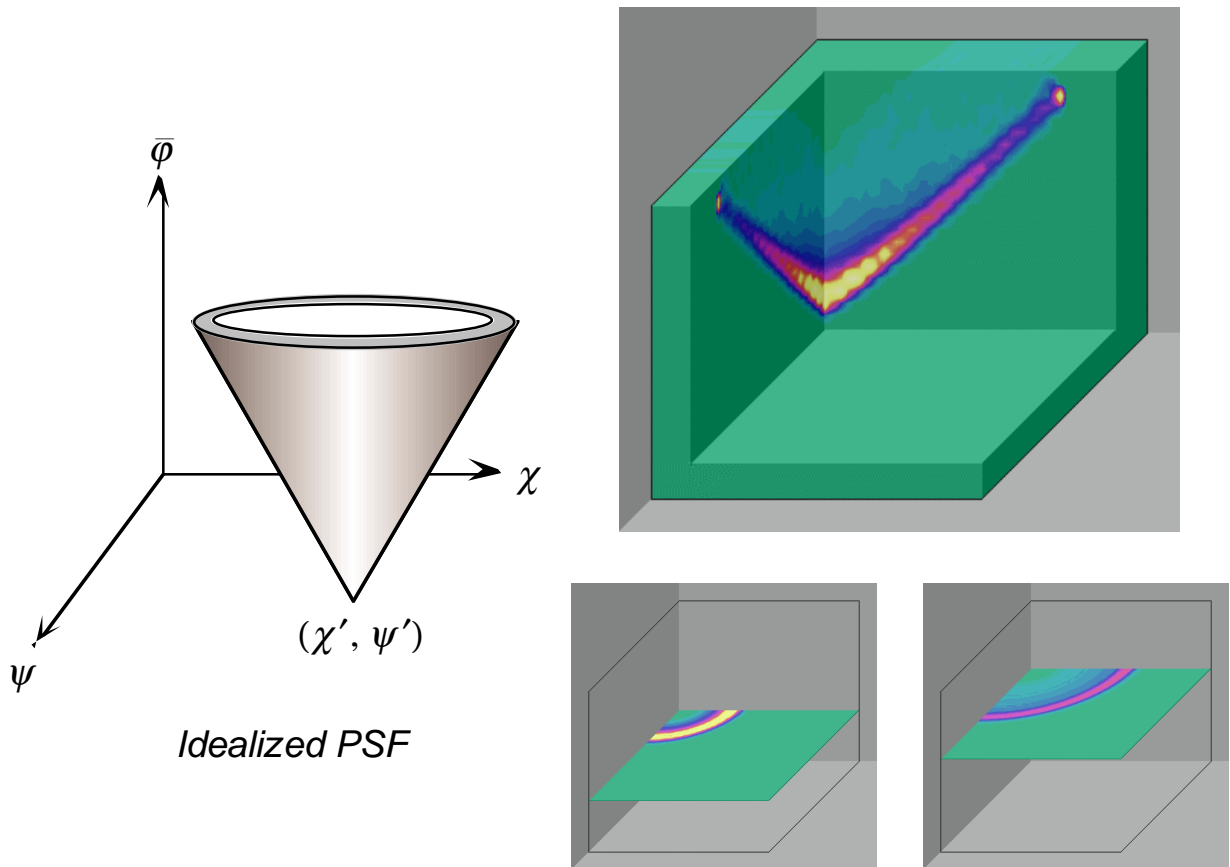
COMPTEL Measurements of the Cosmic Diffuse Gamma-Ray Spectrum

Weidenspointner (2000)

In preparation (for A&A)

The COMPTEL Instrumental-Line Background

The COMPTEL 3-d Dataspace



Simulated PSF for a 2.2 MeV point source.

For a specified energy range, we can define a 3-d distribution of events. *This distribution was always assumed to be symmetric.*

The 3-dimensional dataspace is defined by:

- 1) the photon scatter direction (χ, ψ)**
- 2) the photon scatter angle (ϕ)**

Imaging Reconstruction Techniques

Image reconstruction involves some process which correlates the PSF with the measured 3-d dataspace.

Two standard methods used with COMPTEL data:

- 1) maximum entropy – defines the gross structure.
Seeks the flattest image which is consistent with the measured data. Generates flux distribution maps.
- 2) maximum likelihood – quantitative analysis.
At each point it determines the likelihood of a model containing a point source plus background versus a model containing only background. Generates likelihood maps

Both methods require some independent estimate of the distribution of background events within the 3-d dataspace.

Background Modeling

Several modeling methods have been developed :

- 1) **High-Latitude Background** – Uses observations at high galactic latitudes to estimate a background for low galactic latitude.
- 2) **Dataspace Smoothing (SRCLIX)** – Performs a smoothing within the measured 3-d dataspace which removes the high-frequency (source) components and maintains the low-frequency (background) components.
- 3) **Synthesis Using Adjacent Energy Bands (BGDLNE)** – Uses independent estimate of the (χ, ψ) distribution from adjacent energy bands in conjunction with the ϕ distribution from the energy band of interest. Sensitive to line emission only (e.g., ^{26}Al at 1.8 MeV).
- 4) **Physical Background Modeling** – Seeks to determine the source of all background components. Uses Monte Carlo modeling to generate background estimate. (Never fully developed.)

COMPASS

COMPTEL Processing and Analysis Software System

**Includes both simulation and data analysis tools
(maximum entropy, maximum likelihood).**

**In principle, COMPASS tools could be used with
ACT simulations if the event message is written out
like that of COMPTEL. *Not clear that this would be
of any great value to the ACT effort, however.***

INTEGER*2 - X-location in D1 (in mm, scaled by a factor of 32)
INTEGER*2 - Y-location in D1 (in mm, scaled by a factor of 32)
INTEGER*2 - Lambda location in D1 (scaled by a factor of 256)
INTEGER*2 - X-location in D2 (in mm, scaled by a factor of 32)
INTEGER*2 - Y-location in D2 (in mm, scaled by a factor of 32)
INTEGER*2 - Lambda location in D2 (scaled by a factor of 256)
INTEGER*2 - PSD (scaled by a factor of 128)
INTEGER*2 - ToF (scaled by a factor of 128)
INTEGER*2 - Module Combination
INTEGER*2 - Rejection Flag
INTEGER*2 - Veto Flag
INTEGER*2 - TJD
INTEGER*4 - COMPASS tics
REAL*4 - D1 Energy Deposit (keV)
REAL*4 - D2 Energy Deposit (keV)
REAL*4 - Phibar (radians)
REAL*4 - Photon scatter direction, galactic longitude (radians)
REAL*4 - Photon scatter direction, galactic latitude (radians)
REAL*4 - Photon scatter direction, spacecraft azimuth (radians)
REAL*4 - Photon scatter direction, spacecraft zenith (radians)
REAL*4 - Earth horizon angle (radians)
CHAR*8 - Event Classification

Some Random Thoughts

- **How do we generate a wide FoV map when the PSF varies (dramatically) within the FoV?**

COMPTEL maps are generated by using a single PSF throughout the entire FoV.

- **How do we generate a large number of PSFs as a function of incident photon spectrum and direction.**

COMPTEL relied mostly on brute force simulations, but we also developed a way to synthesize PSFs.

- **The COMPTEL approach originally evolved out of limited resources (slower computers!).**

Developed synthesis approach. Abandoned use of the CGRO Mass Model because it was too slow to be useful.

- **The COMPTEL PSFs were always assumed to be symmetric (i.e., symmetric cones in 3-d space).**

At some level, this assumption is likely to break down due, for example, to variations in detector thresholds.

More Random Thoughts

- **Is it feasible to come up with a background model based on known physics?**

Requires an accurate model for activation as a function of time. Perhaps GEANT4 can do the activation, but we then need accurate models for the incident particle flux (energy and angular distributions).

- **Would 3-d imaging make it possible to map out background distributions within the spacecraft?**

Haskins & MacKisson had GI program to attempt this with COMPTEL data : Phase 3 proposal, “Near-Field Imaging for Discrimination of Locally-Produced Gamma-Ray Background on COMPTEL.”